PERKIN-ELMER

OPTICAL GROUP NORWALK, CONNECTICUT

ENGINEERING REPORT NO. 8691

PHASE III REPORT
GIANT APERTURE TELESCOPE STUDY

DATE: FEBRUARY 20, 1967

JPL Contract No. 951288

PREPARED FOR: CALIFORNIA INSTITUTE OF TECHNOLOGY
JET PROPULSION LABORATORY
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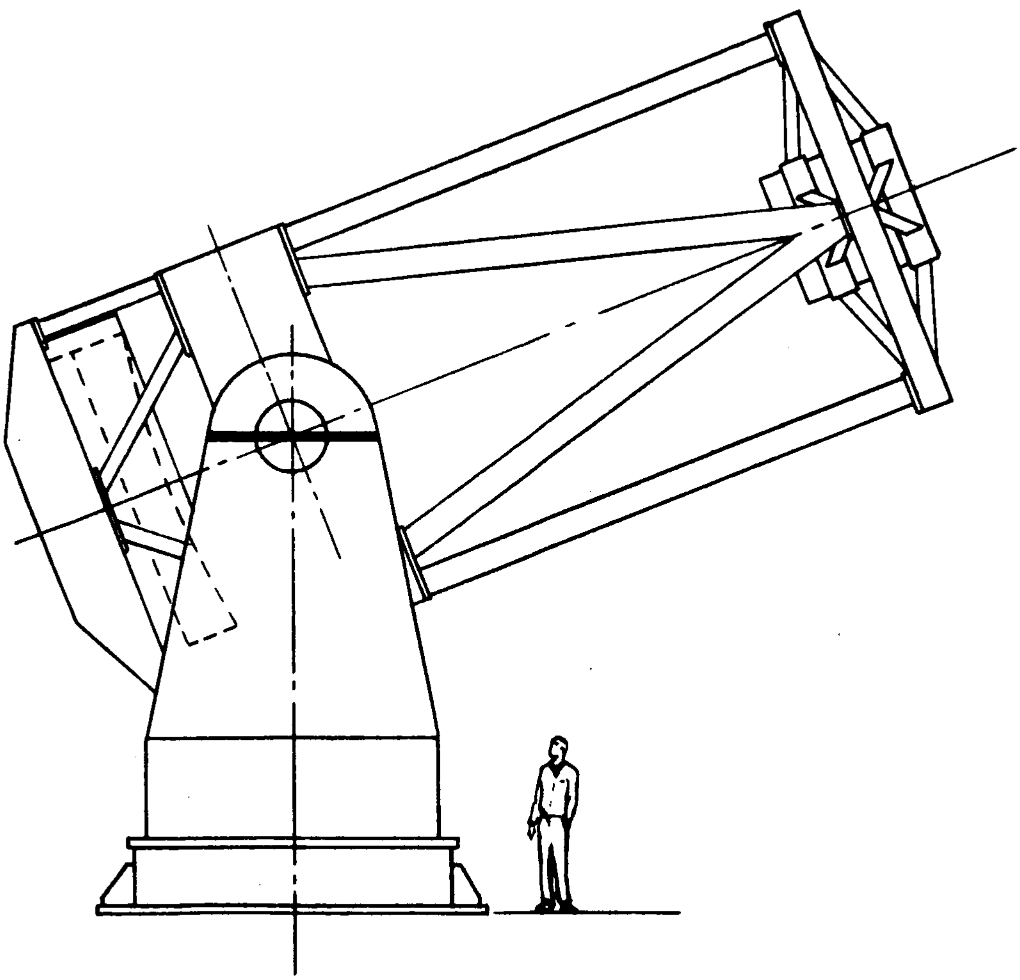
SPO 27252



120-Inch Aperture Azimuth-Elevation Communications Receiver

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SECTION I

INTRODUCTION

This report presents the results of the third and final phase of a design study directed towards determining the optimum configuration, and corresponding engineering guidelines for a ground station for a deep-space optical communications system.

Phase I consisted of broad examination of alternative approaches, with particular emphasis on a comparison of coherent detection and intensity detection techniques. The results of this effort are documented in Perkin-Elmer Engineering Report No. 8393.

The Phase II effort consisted of a detailed study of the specific configuration selected by JPL from the alternatives described in the Phase I Report. The designated approach was a fully steerable telescope appropriate for coherent detection (optical heterodyning) at a wavelength near 10 microns. Aperture diameters from 80 to 120 inches were considered, although major emphasis was placed on the larger number, since its implementation presents the most severe problems. The results of this second phase, comprising the major portion of the study program, appear in Perkin-Elmer Engineering Report No. 8558.

Phase III was initiated following approval of the Phase II Report and upon receipt from JPL of the Technical Direction Memorandom dated 3 January, 1967. It has consisted of a cost study of the instrument studied in Phase II.

SECTION II

COST STUDY

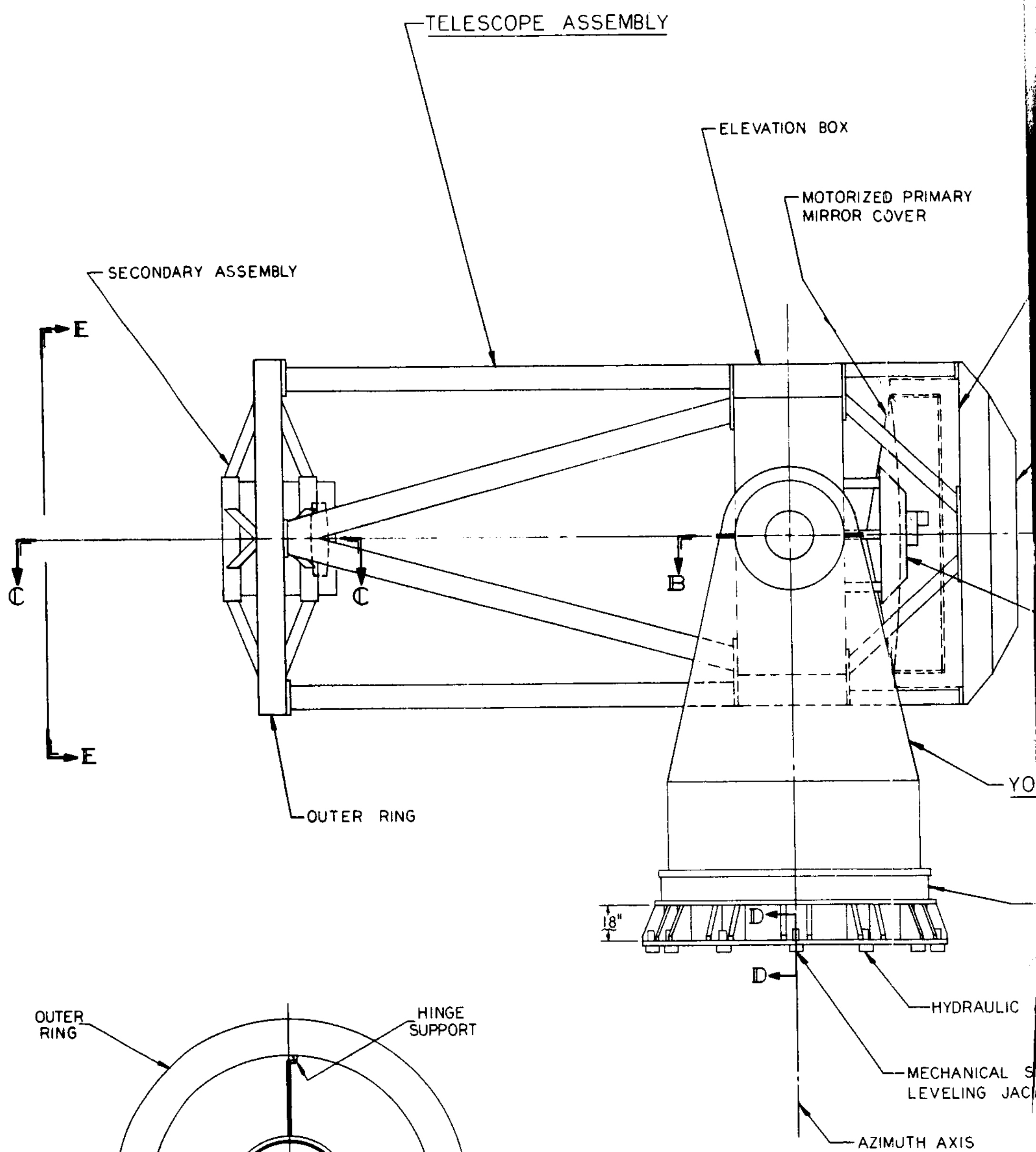
An engineering estimate of the costs associated with the instrument studied in Phase II of this program has been prepared.

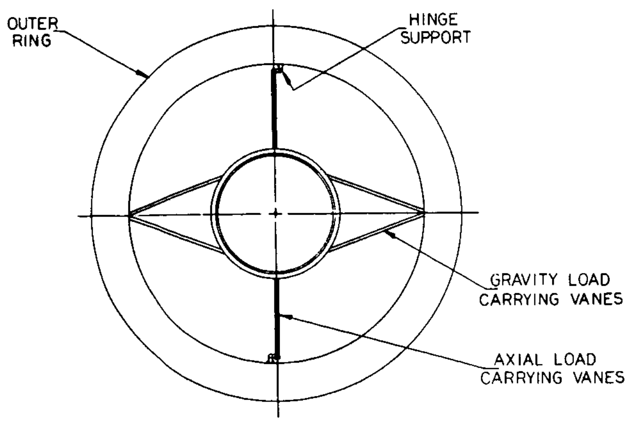
For reference purposes, Figures 1, 2, and 3 illustrate the 120-inch azimuth-elevation telescope, its installation in an elevated dome, and an optical schematic of the telescope and transceiver, respectively. These figures are taken from the Phase II report, however, the frontispiece, Figures 1 and 2 have been modified to reflect JPL's request for deletion of the observer's cage. It should be noted that, in Figure 2, removal of the cage suggests the possibility of a reduction in the size of the dome.

Table I summarizes the estimated first-unit costs of such an installation, while Table II outlines some of the pertinent details. As indicated, the costs for a number of items associated with the building, the site, and auxilliary installations have not been included. These costs are so highly dependent on site characteristics and geographic location that estimates not based on a specific site selection would be realistic at best.

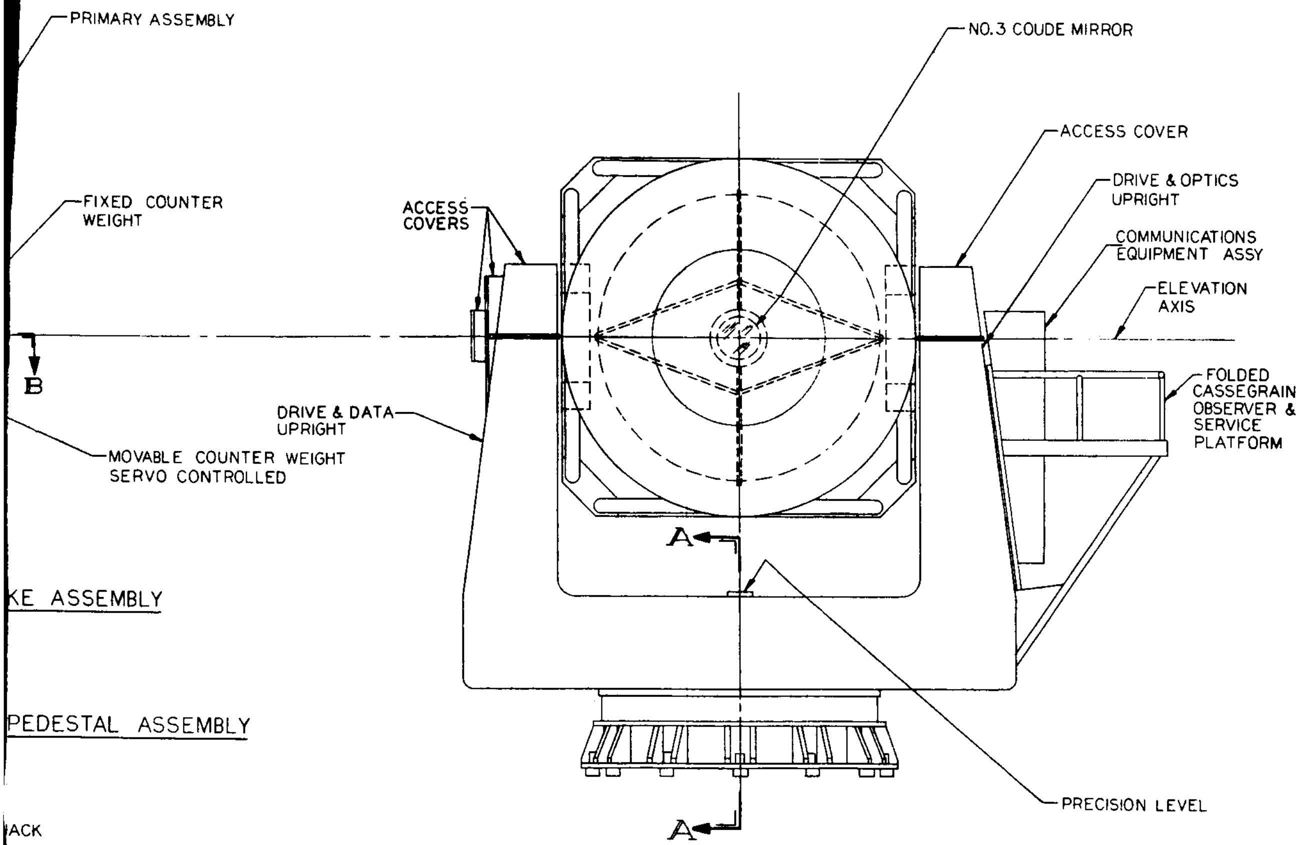
In accordance with JPL's technical directive, the observer's cage and prime focus position have been omitted from the cost estimate.

As shown, the estimated cost for the first installation is $4,006,500 of this amount, it is estimated that $1,210,000 represents non-repetitive engineering


TELESCOPE ASSEMBLY
ELEVATION BOX
MOTORIZED PRIMARY MIRROR COVER
SECONDARY ASSEMBLY
E
C
C
B
E
OUTER RING
18"
D
D
HYDRAULIC
MECHANICAL S
LEVELING JAC
AZIMUTH AXIS
YO


OUTER RING
HINGE SUPPORT
GRAVITY LOAD CARRYING VANES
AXIAL LOAD CARRYING VANES

VIEW E-E



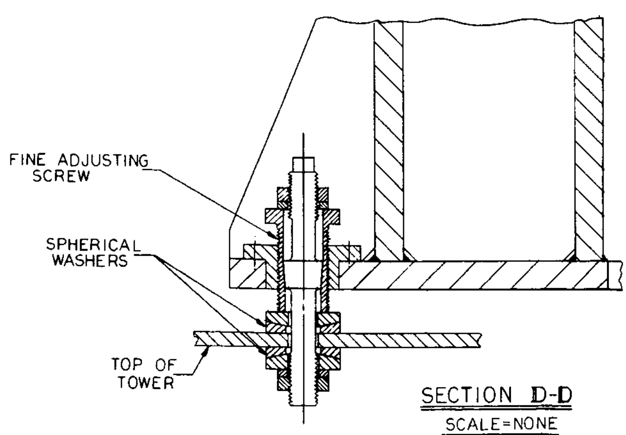
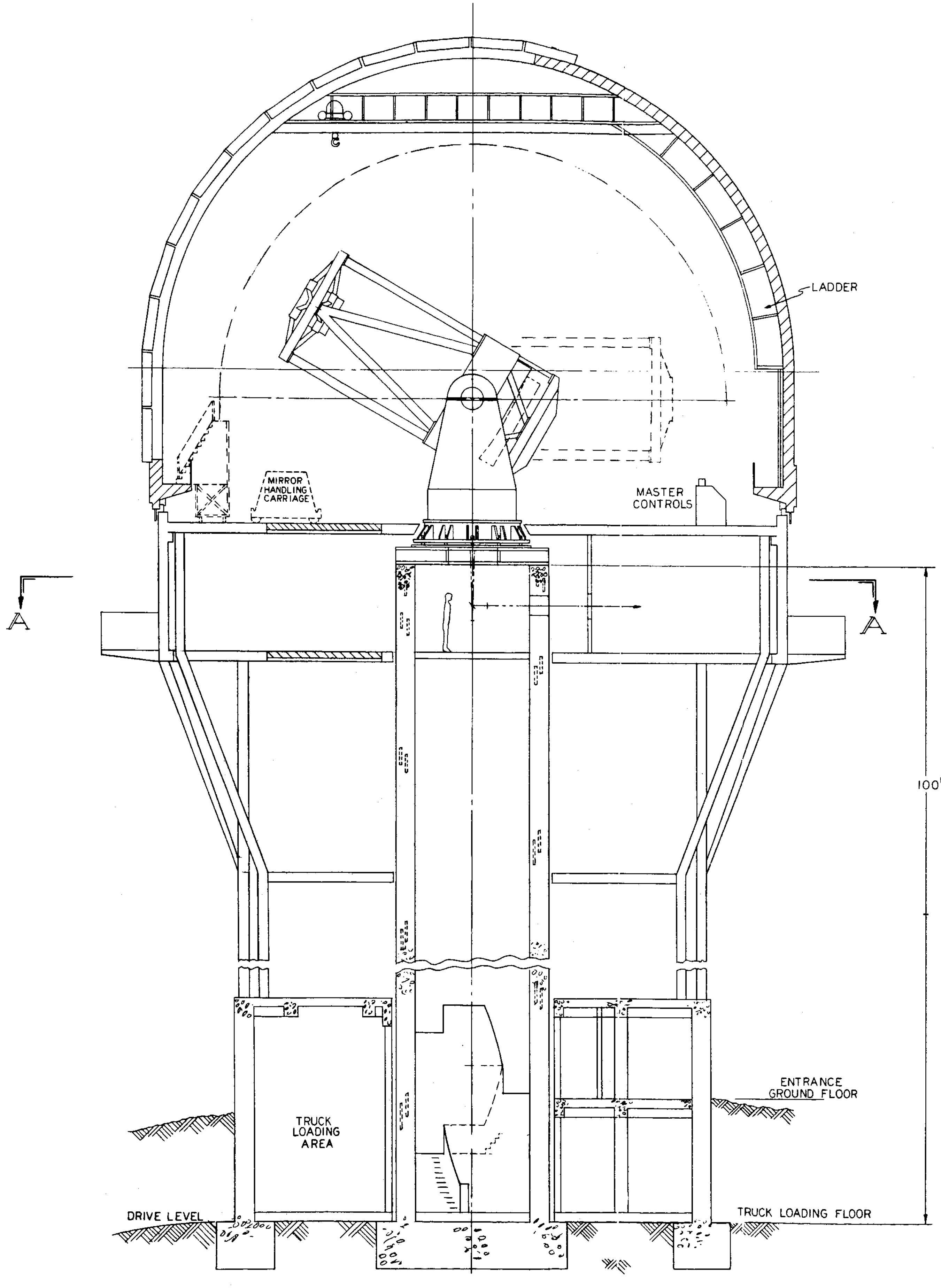
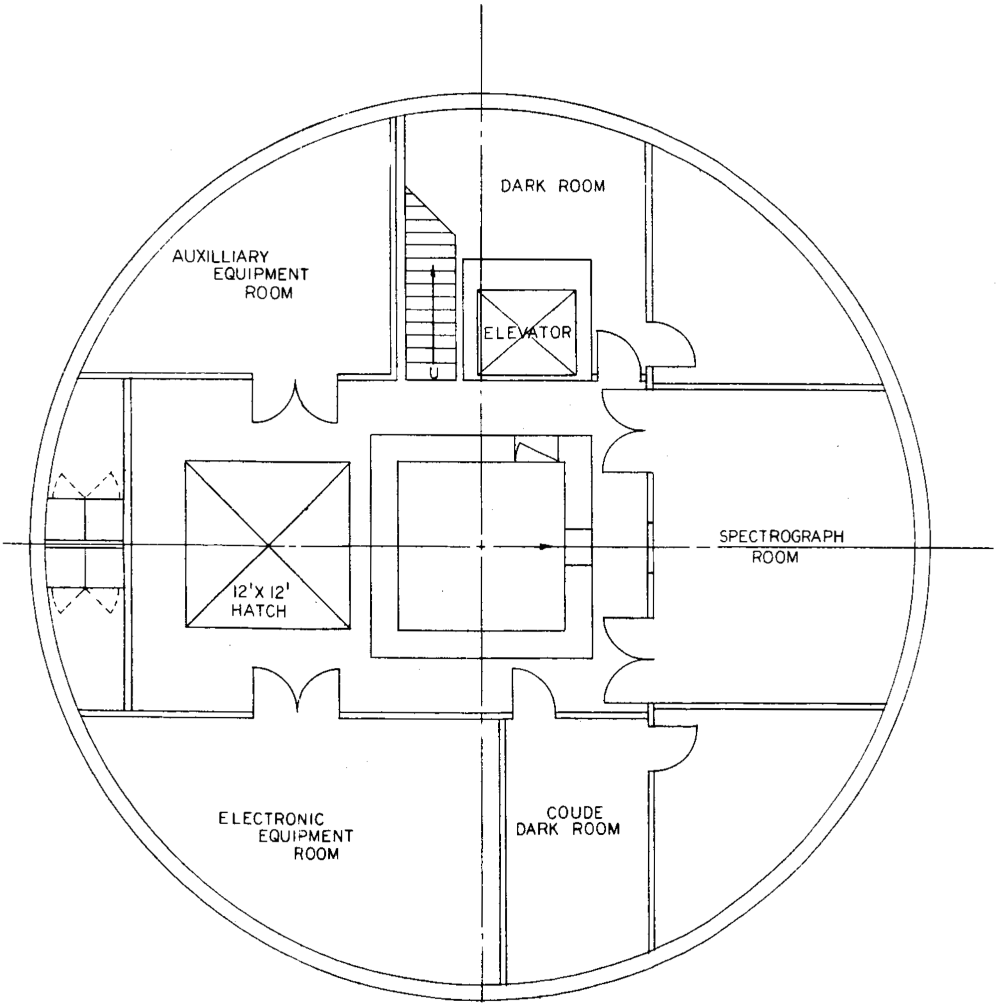


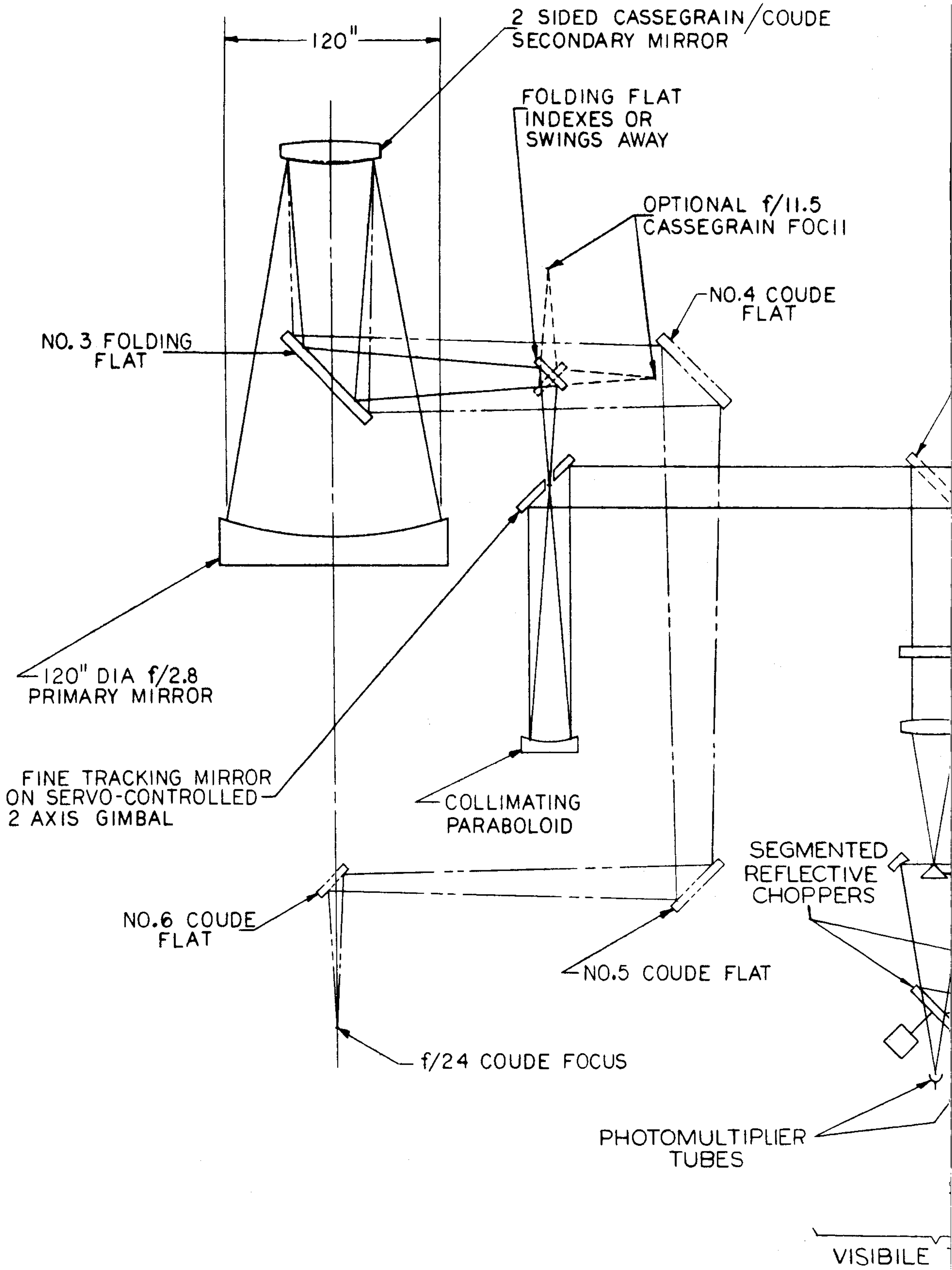
Figure 1. 120-Inch Aperture Azimuth-Elevation Communications Receiver


LADDER
MIRROR HANDLING CARRIAGE
MASTER CONTROLS
A
A
100'
TRUCK LOADING AREA
ENTRANCE GROUND FLOOR
DRIVE LEVEL
TRUCK LOADING FLOOR



PLAN VIEW A-A

Figure 2. Building and Dome - 120-inch Aperture Azimuth Elevation Communication Receiver


2 SIDED CASSEGRAIN/COUDE SECONDARY MIRROR
120"
FOLDING FLAT INDEXES OR SWINGS AWAY
OPTIONAL f/11.5 CASSEGRAIN FOCII
NO.4 COUDE FLAT
NO. 3 FOLDING FLAT
120" DIA f/2.8 PRIMARY MIRROR
FINE TRACKING MIRROR ON SERVO-CONTROLLED 2 AXIS GIMBAL
COLLIMATING PARABOLOID
SEGMENTED REFLECTIVE CHOPPERS
NO.6 COUDE FLAT
NO.5 COUDE FLAT
f/24 COUDE FOCUS
PHOTOMULTIPLIER TUBES
VISIBILE

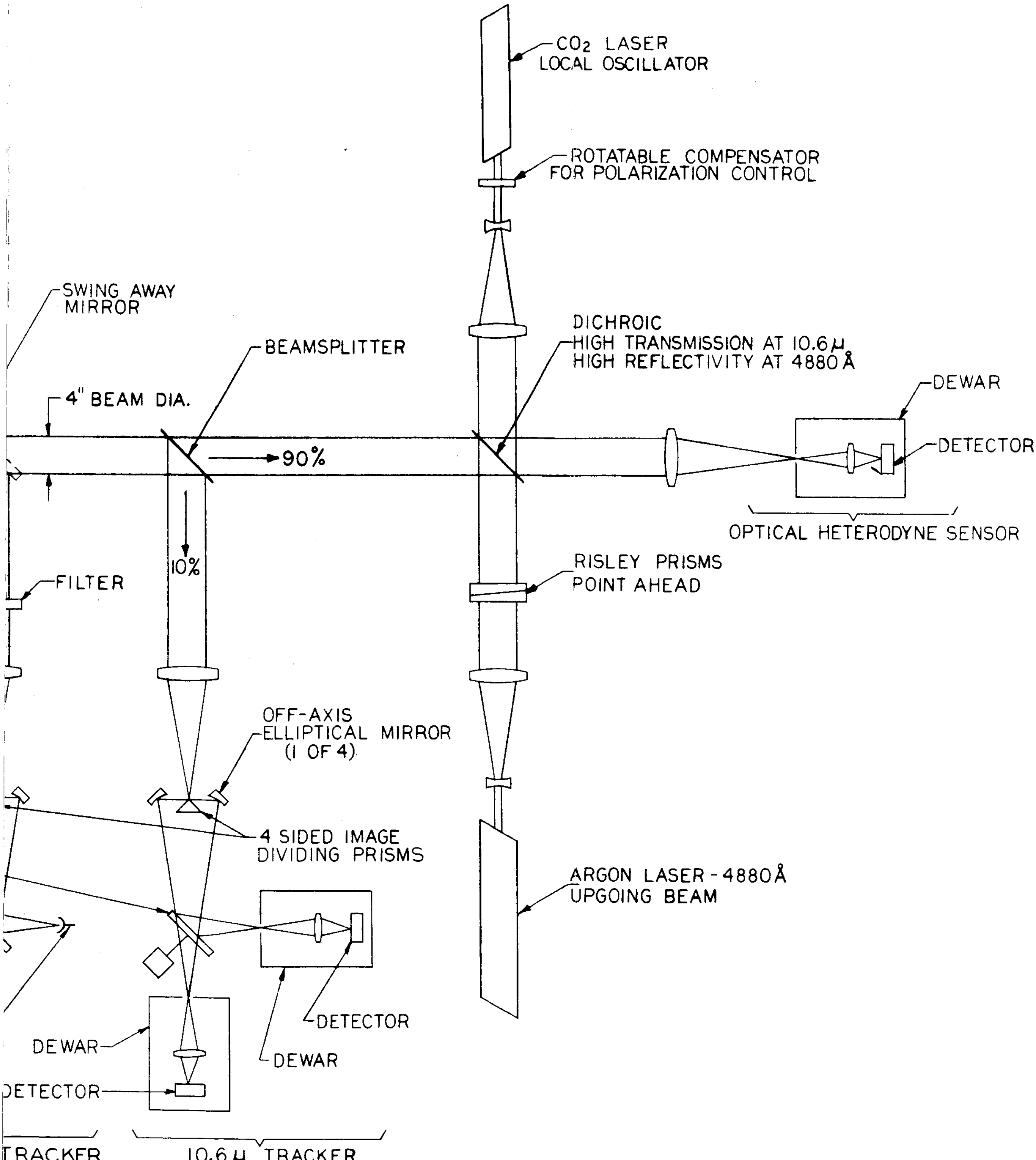


Figure 3. 120-Inch Aperture Communications Receiver Optical Schematic

and design costs. The estimated cost of additional similar installations is thus $2.8 million.

It is estimated that a minimum of three years would be required to complete an installation of this type. This estimate must be qualified, however, with the observation that research and development effort is required in several areas before a full-scale program can be realistically initiated. The major items in this category are:

1. Atmospheric coherence diameter studies at 10.6 microns.

2. A suitable high-power argon laser for the up-going beam which is used for spacecraft guidance.

3. A stable, tunable CO_2 laser for the local oscillator.

TABLE I

COST SUMMARY

		($000's)	
1.0	Telescope Pedestal	371.5	
2.0	Yoke	304.5	
3.0	Telescope Structure	278.5	
4.0	Optics	1,315.5	
5.0	Transceiver	1,051.5	
6.0	Auxiliary Equipment	685.0	
	Grand Total		4,006.5

TABLE II

COST DETAILS

		Engineering	Manufacturing ($000's)	Total
1.0	**TELESCOPE PEDESTAL**			
1.1	Concrete with Base Ring	5.0	1.0	
1.2	Lower Bearing Structure	30.0	25.0	
1.3	Thrust Bearing Race Assembly	12.5	10.0	
1.4	Leveling Mechanism	15.0	12.0	
1.5	Electrical Junction Terminals	7.5	5.0	
1.6	Slip Ring Stack	5.0	20.0	
1.7	Azimuth Read-out Encoders	5.0	45.0	
1.8	Hydrostatic Bearing Subsystem	45.0	30.0	
1.9	Azimuth Brakes	15.0	3.0	
1.10	Local Operator Control	15.0	5.0	
1.11	Azimuth Servo System	12.5	40.0	
1.12	Assembly	--	8.0	
	Subtotal	167.5	204.0	371.5
2.0	**YOKE**			
2.1	Yoke Weldment	40.0	60.0	
2.2	Left-hand Bearing	12.5	12.0	
2.3	Right-hand Bearing	12.5	10.0	
2.4	Observer Service Platform	12.5	4.0	
2.5	Electrical Junction Terminals	7.5	5.0	
2.6	Twist Cable	2.5	3.0	
2.7	Elevation Readout Encoders	2.5	25.0	
2.8	Elevation Servo System	12.5	30.0	
2.9	Elevation Brakes	15.0	3.0	
2.10	Assembly	--	35.0	
	Subtotal	117.5	187.0	304.5

TABLE II (Continued)

		Engineering ($000's)	Manufacturing ($000's)	Total ($000's)
3.0	TELESCOPE			
3.1	Structural Tube	35.0	40.0	
3.2	Secondary Structure	5.0	7.0	
3.3	Primary Structure	20.0	15.0	
3.4	Counter Weight Servo	2.5	4.0	
3.5	Counter Weight Mechanism	7.5	10.0	
3.6	Mirror Cover Mechanism	15.0	12.0	
3.7	Secondary Focus Servo	7.5	4.0	
3.8	Tube Thermal Control	15.0	10.0	
3.9	Tube Baffling	12.5	10.0	
3.10	Dew Covers and Heaters	12.5	7.0	
3.11	Boresight Telescope	5.0	10.0	
3.12	Assembly	--	12.0	
	Subtotal	137.5	141.0	278.5
4.0	OPTICS			
4.1	Primary	15.0	955.0	
4.2	Secondary	7.5	90.0	
4.3	No. 3 Coude Flat and Cell	5.0	62.5	
4.4	Optical Design	20.0	3.0	
4.5	Primary Cell	17.5	100.0	
4.6	Secondary Cell	10.0	30.0	
	Subtotal	75.0	1,240.5	1,315.5

TABLE II (Continued)

		($000's)		
		Engineering	Manufacturing	Total
5.0	TRANSCEIVER			
5.1	2-Axis Tracking Mirror Servo	15.0	10.0	
5.2	No. 4, 5, 6 Coude Flats	10.0	3.0	
5.3	Transceiver Structure and Packaging	50.0	50.0	
5.4	Collimator Parabola	5.0	1.0	
5.5	Swing-Away Mirror	2.5	1.0	
5.6	Beamsplitter	--	1.0	
5.7	Narrow Band Filter 6328Å Spike Pass	--	3.0	
5.8	Dichroic Pass 10.6 Reflect. 4880Å	--	3.0	
5.9	Visible Light Tracker	30.0	15.0	
5.10	10.6 Micron Tracker	45.0	35.0	
5.11	10.6 Micron Cryogenics and Detectors	17.5	15.0	
5.12	200-watt Argon Laser System	130.0	250.0	
5.13	Risley Prism Servo Assembly	15.0	12.0	
5.14	Stable and Tunable 10.6μ local oscillator Laser with single Side-band Shifter	37.5	20.0	
5.15	Detector Electronics	37.5	15.0	
5.16	Transmitter Modulator	2.5	10.0	
5.17	Communications Electronics	60.0	40.0	
5.18	Transceiver Assembly	10.0	100.0	
	Subtotal	467.5	584.0	1,051.5

TABLE II (Continued)

		Engineering	Manufacturing	Total
		($000's)		
6.0	AUXILIARY EQUIPMENT			
6.1	Pointing Control Station	15.0	20.0	
6.2	Equatorial Altitude Azimuth Converter	2.5	85.0	
6.3	Transmitter Control Station	5.0	10.0	
6.4	10.6μ Control Station	5.0	10.0	
6.5	Cryogenics Control Station	12.5	10.0	
6.6	Hydraulic and Hydrostatic Control Station and P.S.	40.0	35.0	
6.7	Boresight Tower	15.0	20.0	
6.8	Boresight Tower Optics	5.0	3.0	
6.9	Boresight Tower Laser	--	7.0	
6.10	Spacecraft Station Display	20.0	10.0	
6.11	Spacecraft Status Display	50.0	30.0	
6.12	Telemetry Data Quick-Look Display	75.0	200.0	
	Subtotal	245.0	440.0	685.0
	Grand Total	1,210.0	2,796.5	4,006.5

NOTE:

The following items have not been included in this estimate:

Auxiliary Power Station	Erection Costs of Site
Dome	Local Digital Computer
Building and Building Services	Data Tape Recording
Water Cooling System	Site Development
Air Conditioning Plant	Roads
Transportation Costs to Site	Living Quarters

APPENDIX A

ERRATA FOR PHASE I AND PHASE II REPORTS

Phase I Report (Perkin-Elmer Report No. 8393)

Page 22, line 10: Replace "bandwidth equal to 1 and 10 mc/s" with "bandwidth equal to 0.2 and 2.0 mc/s".

Phase II Report (Perkin-Elmer Report No. 8558)

Page 44, line 16: Sentence beginning "A straight line ..." should be omitted.

Page 44, line 18: Sentence beginning "Note that ..." should read, "Note that the system is substantially less sensitive to tilts of the secondary than to tilts of the primary, and that lateral displacements of the two mirrors in the same directions introduce pointing errors which are of opposite sign and hence at least partially cancel."

Pages 45-48: Replace Figures VI-1 through VI-4 with the attached revised versions thereof.

Page 112: Receiver Field of View = 10 arc-seconds = <u>48.5</u> μradians (not 4.85 μradians)

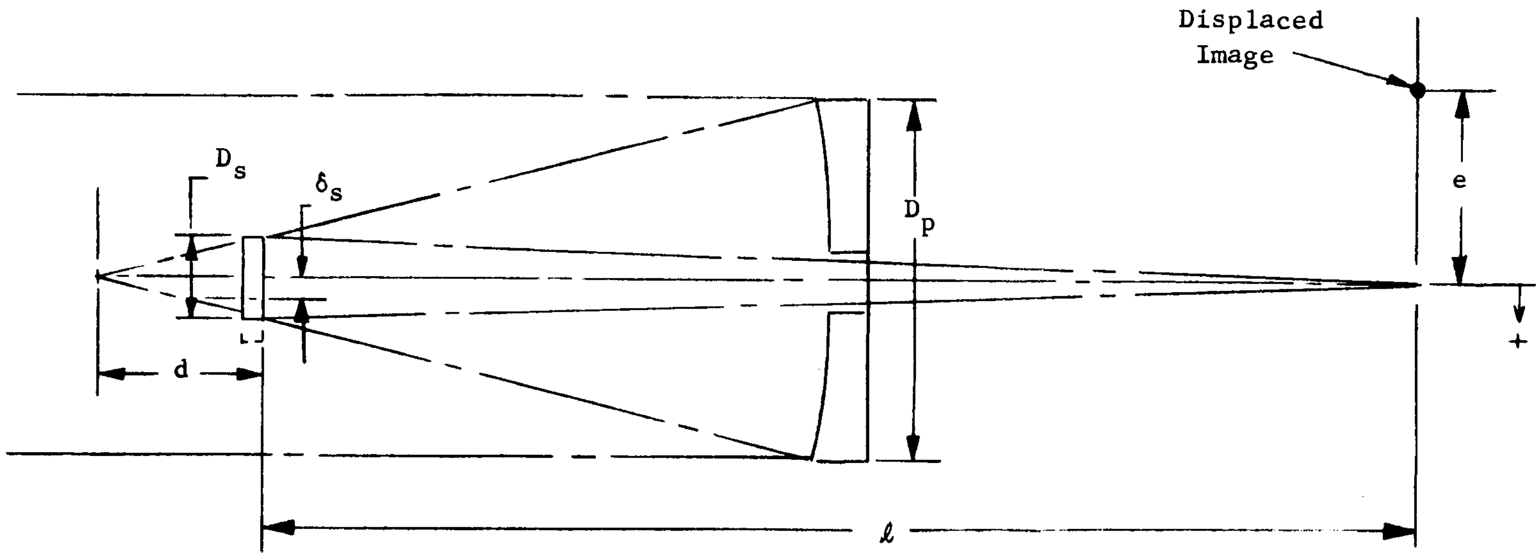
Page 120, line 2: Sentence beginning "As shown ..." should read, "As shown in Figure VI-3 (Revised), the system is relatively insensitive to tilts of the secondary mirror."

$$d = D_s N_p$$

$$\ell = D_s N_s$$

$$EFL = D_p N_s$$

$$N = f/no.$$



Defining positive displacements downwards, the image displacement due to a lateral secondary displacement δ_s is

$$e = -\delta_s \left(\frac{N_s}{N_p} - 1 \right)$$

In angular terms,

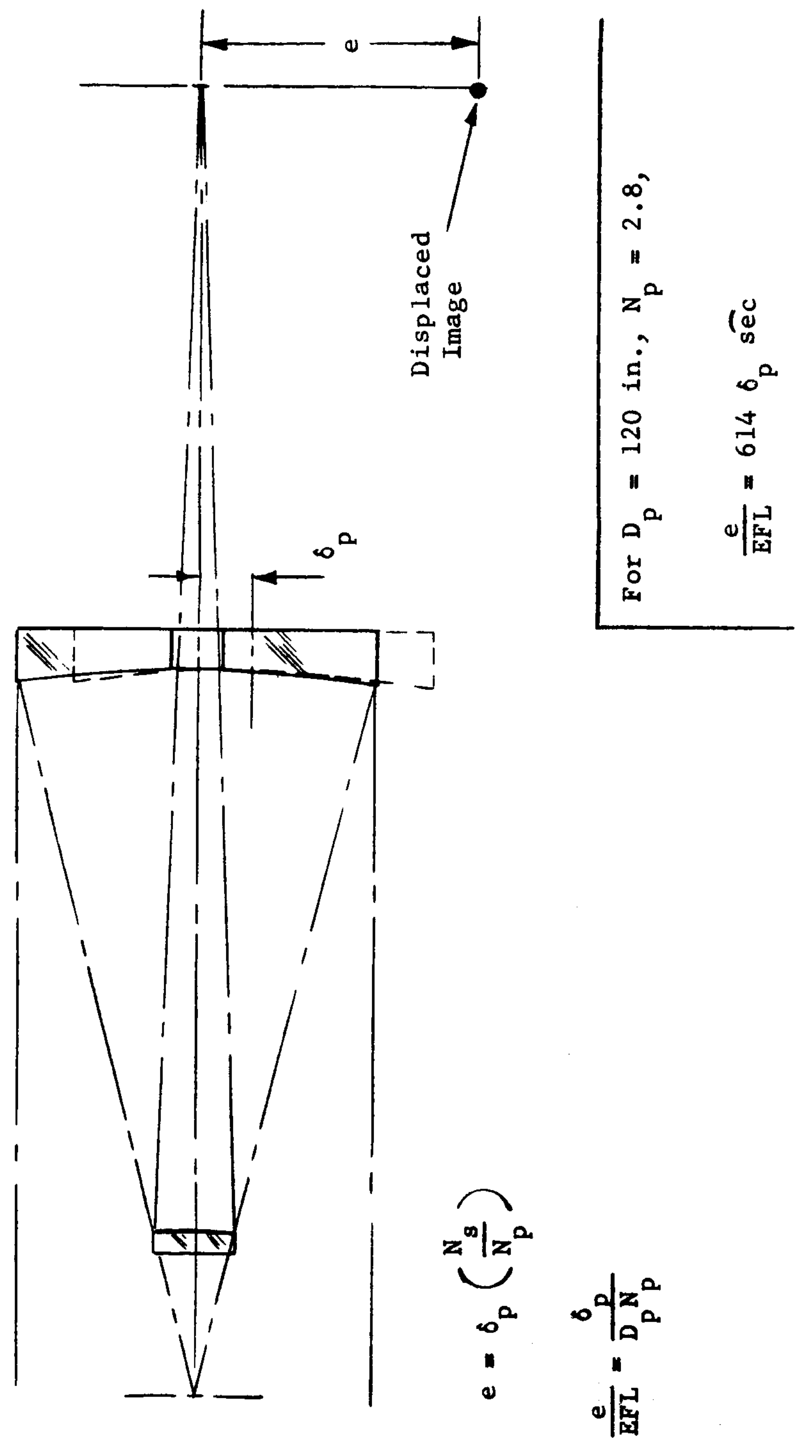
$$\frac{e}{EFL} = - \frac{\delta_s (N_s - N_p)}{N_p N_s D_p} = - \frac{\delta_s}{D_p} \left(\frac{1}{N_p} - \frac{1}{N_s} \right)$$

For $D_p = 120$ in., $N_p = 2.8$,

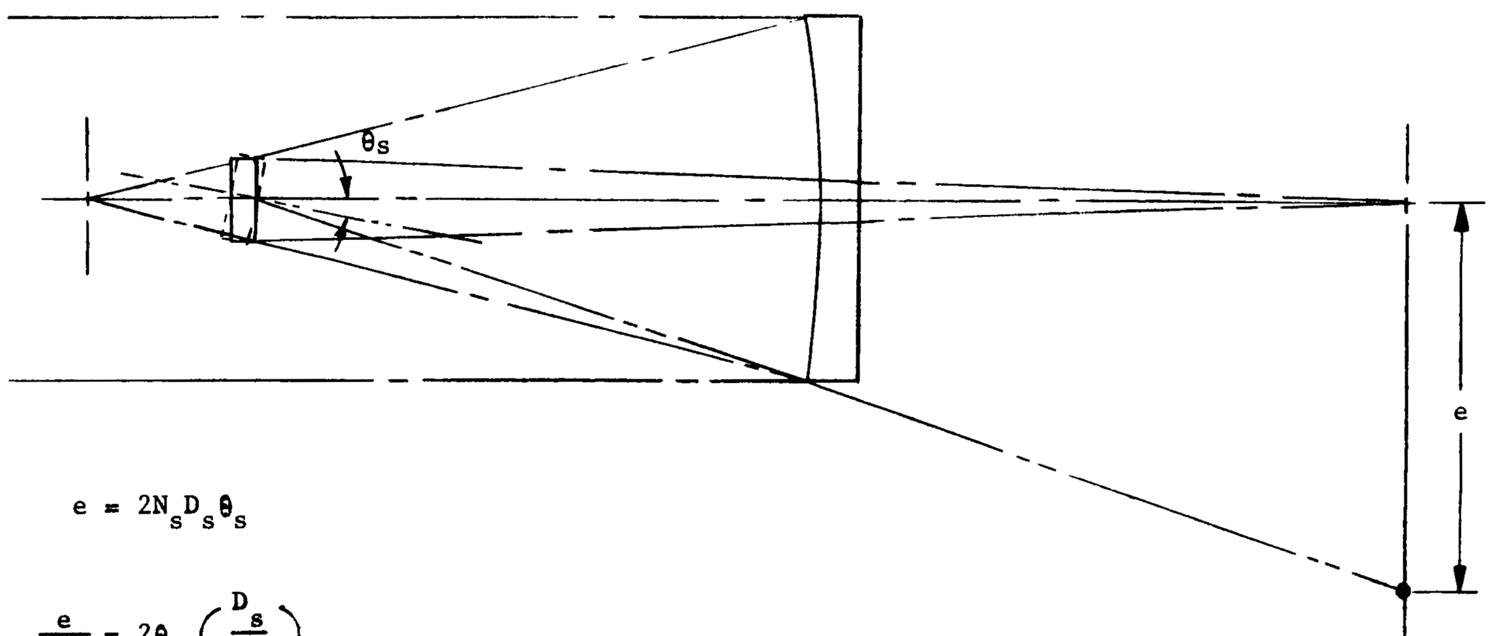
N_s	11.5	24
$\frac{e}{EFL}$	$-465\ \delta_s\ \widehat{sec}$	$-537\ \delta_s\ \widehat{sec}$

(δ_s in Inches)

Report No. 8558 - Figure VI-1. (Revised) Lateral Displacement of Secondary Mirror



Report No. 8558 - Figure VI-2. (Revised) Lateral Displacement of Primary Mirror



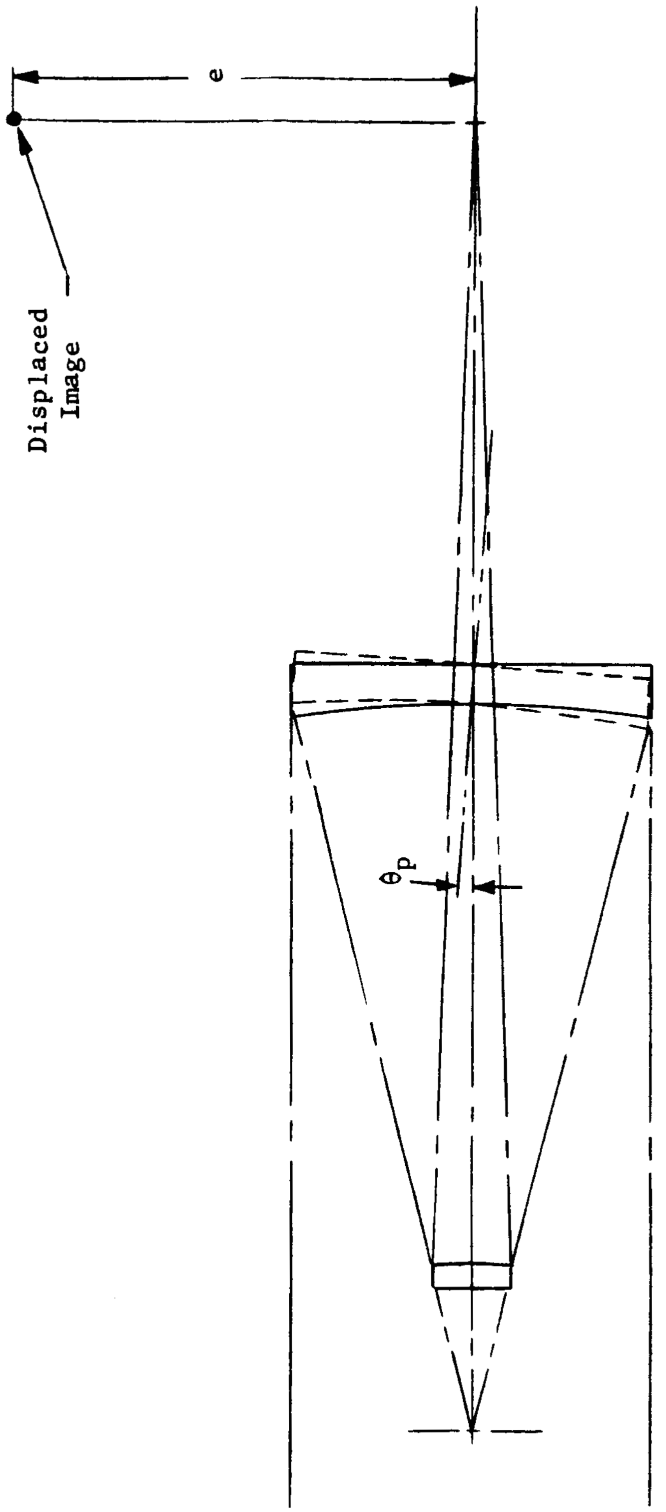
$e = 2N_s D_s \theta_s$

$\frac{e}{EFL} = 2\theta_s \left(\frac{D_s}{D_p}\right)$

For $D_s = 30$ in., $D_p = 120$ in.,

$\frac{e}{EFL} = \theta_s/2$

Report No. 8558 - Figure VI-3. (Revised) Tilt of Secondary Mirror



$$e = -2\theta_p N_p D_p \left(\frac{N_s}{N_p}\right) = -2\theta_p N_s D_p$$

$$\frac{e}{EFL} = -2\theta_p$$

$$\frac{e}{EFL} = -2\theta_p$$

Report No. 8558 - Figure VI-4. (Revised) Tilt of Primary Mirror